NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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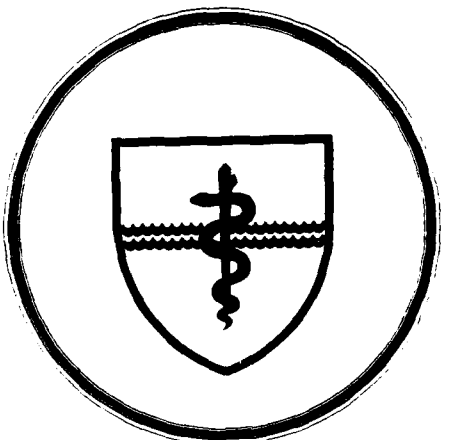

Memo Rpt. 88-2

Power Plant Fuel Consumption: A linear and rule based system

by

Kendall J. Bryant, Ph.D.

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

Released by:

C. A. HARVEY, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

19 September 1988

Approved for public release; distribution unlimited

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SUMMARY PAGE

THE PROBLEM

To predict Naval Submarine Base power plant fuel consumption.

THE FINDINGS

A regression equation was developed.

APPLICATION

Through the use of the equation, power plant personnel are able to identify significant deviations in fuel consumption during any operating period using a hand calculator.

ADMINISTRATIVE INFORMATION

This report is the result of a request by LCDR Vern King, Public Works Department, Naval Submarine Base New London, Groton, CT. It was submitted for review on 18 August 1988, approved for publication on 19 September 1988, and designated as NSMRL Memo Report No. M88-2.

ABSTRACT

A regression equation was developed to predict Naval Submarine Base power plant fuel consumption throughout the year. Fuel consumption was based on generator characteristics and seasonal characteristics [1]. Both linear prediction and rule based information were combined to obtain an accurate prediction of fuel consumption. The resulting regression equation estimates past fuel consumption from seasonal (degree day) and power plant characteristics with over 90% accuracy.

Through the use of the equation, power plant personnel are able to identify significant deviations in fuel consumption during any operating period using a hand calculator. The equation has proved to be an effective diagnostic and management tool [2].

INTRODUCTION

The power plant on the U.S. Naval Submarine Base faces some unusual problems in providing electric power. Not only must they take into account the usual seasonal fluctuations, but they have such additional problems as, for example, the coming and going of the submarines. This produces wide and unpredictable fluctuations in the amount of power which must be provided at any given time. The power plant needs a simple method of calculating the amount of fuel that will be used under different circumstances and for predicting the amount of fuel that will be used under various conditions.

A regression equation was developed to predict fuel consumption throughout the year. Fuel consumption was based on generator and seasonal characteristics. Linear prediction and rule based information were combined produce a regression equation which estimates fuel consumption.

METHOD

Fuel plant consumption was estimated on a monthly basis from January of 1985 through April of 1988, a period of 40 months. During that period the plant was repaired and a main boiler replaced.

Primary Variables: Generated electricity (GEN) was measured in Megawatts per hour (X=2208.6, sd=884.017). Fuel (FUEL) was measured in thousands of gallons (X=551.653, sd=103.372). Heating degree days (DDAYS)was measured as the daily ratio of fuel consumption and mean temperature under 65 degrees Fahrenheit (X=466.225, sd=401.763).

Rules for Effects: Two sources of inefficiency were present in the generator system. The first was the need to run all generators on standby irrespective of power demands. The second was an inefficiency in the turbine characteristics when a high rate of electricity at near peak capacity was demanded. The rules (INEFF) that were developed to handle these conditions were:

a) DDAYS > 600 and GEN < 1600 or b) DDAYS < 100 and GEN > 2800

Rule a and b were dummy coded seperately and forced into the regression equation simultaneously to obtain their combined effect.

Repair Period: A period in which the boiler was failing and then was replaced was also evaluated for effects on fuel consumption and included in the equation (NEW). The new boilers were only in place for a 4-month period beginning in January of 1988.

Stepwise multiple regression equations were used with dummy coding for power consumption rules and repair periods. Variables were entered hierarchically and residuals evaluated for outliers and fit to observed data. Cutoffs for rules were adjusted sequentially until the best fit of the predicted values to the observed values for fuel consumption was obtained.

RESULTS

Fuel consumption was first predicted from Heating degree days. This variable accounted for 71% of the variance ($T=9.728$, $p<.001$). Generated electricity was next evaluated accounting for an additional 16% of the variance ($T=6.94$, $p<.001$). Inefficient periods were entered next accounting for an additional 4% of the variance ($T=3.04$, $p<.005$). Finally, an adjustment for the heating system repairs was added which accounted for approximately 2% of the overall variance ($T=2.345$, $p<.05$). Addition of the new boilers decreased fuel consumption by an average of 42 thousand gallons per month during the four month period they were in place. The complete equation for estimating fuel plant consumption in thousands of gallons is given as:

$$\text{Fuel} = .207*\text{DDAYS} + .048743*\text{GEN} + 36.140*\text{INEFF}$$

$$-41.985*\text{NEW} + 344.35$$

Table 1 presents the summary statistics for the regression equation. Overall, the equations predicted 91.4% of the variation with an $F=93.6$, $p<.000$ (df 4,35). The standard error of prediction for the equation was 31.90. The mean predicted value was 551.6525 (sd = 98.85). The constant in the equation indicates that approximately 344 thousand gallons of oil are consumed each month to keep the generators operating without any load.

DISCUSSION

The equation that was developed was successfully used as the basis for power plant management. Actual fuel consumption that fell within the plus or minus 1.5 standard error range of the predicted consumption was considered normal and acceptable. However, greater errors in prediction led to attempts to diagnose problems in fuel consumption. During the 40 month period that was evaluated only four of the residuals of the predicted fuel consumption fell outside this range (2 positive and 2 negative). Given the high precision and predictive power of the equation this is to be expected. Examination of the equation residuals indicates that there are systematic cyclic fluctuations. These changes in fuel consumption may correspond most directly to the number of submarines drawing power while in port. Inclusion of this variable could further improve the predictive power of the equation. However, it would not improve the utility of the equation as a management and diagnostic tool.

Table 1

Multiple R	.95630
R Square	.91450
Adjusted R Square	.90473
Standard Error	31.90690

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	381116.20072	95279.05018
Residual	35	35631.75903	1018.05026

F = 93.58973 Signif F = .0001

---------- Variables in the Equation ----------

Variable	B	SE B	Beta	T	Sig T
DDAYS	.207236	.013593	.805433	15.246	.0000
GEN	.048743	.005909	.416839	8.249	.0000
INEFF	36.140447	12.791558	.141627	2.825	.0077
NEW	-41.985544	17.902839	-.123400	-2.345	.0248
(Constant)	344.350729	14.440151		23.847	.0000

Summary information for prediction of Fuel Consumption (KGAL) from Degree Days (DDAY), Generated Electricity (GEN), Generator Characteristics (INEFF), and Modifications in the Power Plant (NEW).

Footnotes

[1] The data and impetus for the project was provided by LCDR Vern King who enlisted the aid of the Naval Submarine Medical Research Laboratory through LCDR David Southerland and provided the data for the analysis.

[2] The office of the Secretary of the Navy awarded the Naval Submarine Base, New London Public Works Department an Energy Conservation Award for the year 1987. Through the efforts of the Public Works Department, fuel reductions of up to 12% were obtained (see Dolphin, July 21, 1988 for a complete description entitled "Pulling the Plug on Energy Waste").

Disclaimer

This memo report is the result of a request by LCDR Vern King, Public Works Department, Naval Submarine Base New London, Groton, CT. The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government.

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NSMRL Memo Report 88-2	5 MONITORING ORGANIZATION REPORT NUMBER(S) NA
6a NAME OF PERFORMING ORGANIZATION Naval Submarine Medical Research Laboratory 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Naval Medical Research and Development Command
6c ADDRESS (City, State, and ZIP Code) Naval Submarine Base New London Groton, CT 06349-5900	7b ADDRESS (City, State, and ZIP Code) Naval Medical Command National Capital Region, Bethesda, MD 20814-5044
8a NAME OF FUNDING / SPONSORING ORGANIZATION Same as 6a. 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Same as 6b.	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 61 / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
Power plant fuel consumption: A linear and rule based system

12 PERSONAL AUTHOR(S)
Kendall J. Bryant

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
MEMO	FROM 1/85 TO 4/88	19 Sep 1988	5

16 SUPPLEMENTARY NOTATION
This report is the result of a request by LCDR Vern King, Public Works Department, Naval Submarine Base New London, Groton, CT.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB GROUP	(U)Power consumption; (U)Regression equation; (U)Prediction; (U)Degree days; (U)Diagnostics; (U)Management; (U)Power plants

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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20 DISTRIBUTION / AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Susan B. Monty, Publications Office	22b TELEPHONE (Include Area Code) (203) 449-3967 / 22c OFFICE SYMBOL 421

DD Form 1473, JUN 86 — Previous editions are obsolete

S/N 0102-LF-014-6603

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED